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AUTHOR Klopfer, Leopold E.
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ABSTRACT

It is suggested that the dilemma at every level of science education has its roots in the discrepancy among the goals of science education appropriate for different groups of learners. Considered are the major goals of science education as applied to two groups of pupils - the prospective scientists and all students in general. For the prospective scientists, the primary goal of science education is to provide them with the basic preparation for their further professional studies. For every student at all levels, the goals are those which contribute to the individual's scientific literacy. The three components of scientific literacy were identified as (1) understanding of key concepts and principles of science; (2) understanding of the aims and processes of scientific inquiry, and (3) understanding of the interactions between science and the general culture. Based upon these goals of science education, the author speculates upon the key features of science instruction in 1991. He suggests that within secondary schools and colleges there be established two curricular streams: a Prospective Scientists Stream and a Scientific Literacy Stream. Each stream was discussed with examples of the concepts to be studied and instructional procedures to be used in the elementary school, secondary school, and college. (RR)

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LEOPOLD E. KLOPFER

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SCIENCE EDUCATION IN 1991

Leopold E. Klopfer

Learning Research and Development Center

University of Pittsburgh

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SCIENCE EDUCATION IN 1991[1]

"There is indeed much in what you say, . . .
One can look back a thousand years easier
than forward fifty."

-- Edward Bellamy (1888)

Science education in the last decade of the twentieth century will differ importantly from science education today. This will be so because by 1991 science teachers and educators generally will have adopted and adapted the worthwhile innovations originated in our own time, and because the basic dilemma which now underlies the teaching and learning of science cannot remain unresolved. In the past decade, the teaching of science in America has been the focus of countless changes as curriculum revisions on a previously unprecedented scale have swept over the science courses of the high school and, more recently, the science offerings in the elementary and junior high schools and in the colleges. Much has been accomplished and will continue to be accomplished in the years to come. However, despite the great flurry of new science courses, new curricula, new materials, new approaches, the basic dilemma confronting science education has been largely ignored. The numerous course and curriculum improvement projects, concerned rightly with attaining their own objectives and not with matters of policy, have contributed little to the resolution of the dilemma; they have highlighted its urgency.

The dilemma at every level of science education has its roots in the discrepancy among the goals of science education appropriate for different groups of learners. The goals of science education appropriate for those students who will enter careers in science and in fields closely related to science are quite different from the goals of science education for the much

larger proportion of students who will not pursue such careers. Our dilemma arises from the fact that both sets of goals have legitimate claims on the education in science offered in schools and colleges. This is true today, and it will also be true in the last decade of this century.

There is little question today about society's need for research scientists, in reasonably large numbers and of high competence. Not only is the still-accelerating development of scientific understanding the primary hallmark of man's intellectual adventure in our times, but the continually renewed fundamental knowledge won through the efforts of scientists provides the essential base for the growth and survival of all advanced, technologically-oriented nations in the second half of the twentieth century. Concomitant with the need of society for talented men and women to develop our understanding of the natural world, there is an equally important need for strong corps of imaginative people who will fashion the means of design, development, and production that make possible the application of scientific advances for the benefit of man. These are the applied scientists and engineers in industries and in large-scale, government-sponsored projects who serve as the vital articulating backbone of our technological progress. While it is true that in many fields the distinction between fundamental science and the applications of science is rapidly becoming more hazy and may even be artificial, it still seems useful to distinguish the scientist, acting as scholar (-- the historical term "natural philosopher" is particularly apt --), from the engineer, acting as implementer, in terms of the different functions which each performs in society today will perform in the society of 1991.

Another professional whose effective services to society and to man are closely related to the growing understandings of science is the physician.

The practice of medicine, already mightily influenced by the scientific understanding of living processes and interactions on various levels of biological organization, will surely become immeasurably enriched and increasingly sophisticated as a result of the imminent discoveries and breakthroughs in the biomedical areas of science that the next quarter century will witness. As he ministers to the sick and promotes the cure and prevention of diseases of the human body and mind, the modern physician of 1991 will be the implementer par excellence in applying the advances of science to the benefit of man.

These three types of professionals--scientists, engineers, and physicians--all play decisive roles in the dynamic twentieth century society of today and of the decades to come. Although science and technology are expanding rapidly in this country today, the rate of expansion will not diminish, according to most forecasters, in the immediately ensuing years.[2] Thus, the number of scientists and engineers required will be larger in the future. At the same time, since the population of the United States is expected to grow in the coming decades, the number of physicians who will be needed will increase, assuming that the present physician-to-persons ration is maintained or improved. Nevertheless, though the number of scientists, engineers, and physicians in our society will be larger, the proportion of people in the population who are engaged in these professions will probably not increase greatly. Sensible estimates suggest that scientists, engineers, and physicians will in the future, as they do today, constitute somewhere between five and ten per cent of the total labor force in the United States.

For the prospective scientists, physicians, and engineers, the primary goal of their science studies up to the bachelor's degree in college is to obtain the basic preparation for their further professional studies and experiences, in which a sound understanding of science is central. For this reason,

the competencies in science of these students must be developed as broadly and as deeply as possible in the course of their secondary school and undergraduate college years. This goal cannot be attained easily, for the domains of scientific knowledge are already vast and the regular increments to science in new discoveries and ideas sally forth in relentless flood. Since the time available in college alone is not sufficient to encompass all the preparation in science that is required by the aspiring scientist, physician, or engineer, the secondary school was enlisted many years ago in this task. The secondary school sought to respond, and the preparation of students for college science courses became one of the accepted aims of high school science teaching. Numerous high school science teachers now consider this preparation for later science courses to be the principal or only aim of science instruction in the secondary school. It is clear that the goals relating to pre-professional preparation in science are very much in evidence in science education today. The same set of goals will also be evident in science education in 1991.

Yet, there is another important set of goals, in conflict with the goals discussed thus far, that has at least an equal claim on giving direction to the teaching and learning of science. While the goals relating to pre-professional preparation in science are appropriate for students planning to become scientists, physicians, and engineers, only a small minority of the total population is engaged in these professions. Well in excess of ninety per cent of all working people are engaged in occupations that are <u>not</u> directly related to science. This proportion for today will remain essentially the same in 1991. To this must be added the proportion of women who are housewives and mothers, but who are unaccountably designated as "unemployed," and it becomes clear that almost everyone is a non-scientist. For the non-scientist, the goals of his education in science cannot be the same as for the prospective

scientist, physician, or engineer.

The goals of science education appropriate for <u>everyone</u> in schools and colleges are those which will contribute to the individual's scientific literacy. Literacy in science is essential for every man and woman who hopes to function effectively in our twentieth century society. It will enable the individual in a rapidly changing environment to make intelligent choices about his personal well-being. It will provide him with a basis for judging and taking action on issues related to science that affect every citizen. It will enable him to better understand and appreciate the functions of science and technology in a transformed world. Indeed, there is a great deal to be accomplished in developing each student's scientific literacy through his science studies in school and college.

One component of scientific literacy is the understanding of key concepts and principles of science. Even though an individual is not personally engaged in a scientific or science-related occupation, he needs some basic understanding of scientific ideas to be able to comprehend the phenomena and the changes in the natural world in which he lives. Certain commentators have labeled such basic knowledge "survival science." It includes both the functional understanding of key concepts and the recognition of how these concepts apply to the practical affairs of life. "Survival science" consists of the essential knowledge and understanding every individual needs in an age of technology derived from science. Through his understanding of key science concepts and principles, the scientifically literate person is able to choose courses of action which will help him to live in safety and in health.

More important that the understanding of scientific concepts, however, is the component of scientific literacy related to how scientific ideas are developed. George Sarton wrote:

> It is not at all necessary that the average man should be acquainted with the latest theory of the universe or the newest hormone, but it is very necessary that he should understand as clearly as possible the purpose and method of science. This is the business of the schools, not simply of the colleges but of all the schools from kindergarten up.[3]

This comment suggests that a major emphasis in education for scientific literacy must be placed on the process of scientific inquiry. Every student should come to fully comprehend and appreciate what scientists do as they seek understanding of the natural world through the construction of networks of ideas. He must learn how scientific ideas are formulated, tested, and inevitably, revised, and he must learn what impels scientists to engage in this activity. Only if he thoroughly understands the aims and the processes of scientific inquiry will a person's confidence in science and scientists not be undermined when he learns of newly proposed scientific concepts and ideas that flatly contradict the concepts he previously studied in school. The scientifically literate person, with his understanding of scientific inquiry, will be able to accept such reformulations of scientific ideas and will remain unperturbed.

A further crucial component of scientific literacy is an understanding of the interactions between science and the general culture. The understanding of scientific concepts and understanding of scientific inquiry are without substance if the student, who will be the citizen of tomorrow, is unaware of the impact of science and related technologies on contemporary society. Commenting on the need to develop a citizenry properly educated in science, Paul Hurd said that the major goal for science teaching is

> ...to have students develop something more than a commonsense understanding of the natural world and, secondly, to understand science as a cultural asset, both with reference to its intellectual value and its social import. If young people are to take an

> active part in the affairs of our country and behave as rational citizens, they will need to understand not only the scientific enterprise, but its role in technology; and the place of both science and technology in the advancement of mankind.[4]

Perhaps the two most salient features of civilized life in the twentieth century have been the progress made possible by technology in reducing man's physical labor, in communication, in transportation, in increasing material comforts; and the transformations engendered by science in man's thinking and beliefs. A person who is scientifically literate would be cognizant of the multiple interactions between science and the general culture and would incorporate aspects of his understanding into his personal planning, into his political decisions, and into his view of the world.

It is certainly quite obvious that the goals related to the development of scientific literacy are greatly different from the goals related to pre-professional science preparation. Good arguments have been advanced for the importance of both sets of goals in science education. However, scientists, teachers, and educators alike have been constantly confused about which set of goals their science programs and science courses were supposed to achieve. Many are still confused, for both sets of goals are worthy; but both cannot be achieved effectively at the same time in the same classroom as it is presently organized. This is the basic dilemma in science education today.

By 1991, a pattern of science education will have emerged which provides a resolution of our current dilemma. In common with other schemes of educational organization, this pattern will have evolved from its predecessors and will reflect the adjustments that a society inevitably makes in its educational system in order to accomplish its aims of perpetuation and growth.[5] This pattern is a projection of current trends in science education and of current

capabilities in American society for making adjustments in its educational system. Moreover, the projected pattern and the details of the programs within it take account of the best of the innovations already evident today in the teaching and learning of science.

1991

The key feature in the science education pattern of 1991 will be the clear distinction of two curricular streams through the secondary schools and colleges. One curricular stream will be designed for students planning to enter careers as scientists, physicians, and engineers. We shall call this the Prospective Scientists Stream, or PS Stream. The other curricular stream will be designed for students who will become the non-scientist citizenry in all strata of the society, i.e., people who will have careers as housewives, service workers, salesmen, business managers, artists, accountants, government officials, history professors, clergymen, etc. We shall call this the Scientific Literacy Stream, or SL Stream. Differentiation of students into the PS Stream or the SL Stream will begin at about age 14 when they choose the high school they will attend.

In contrast with the usual instructional practices of today, the study of science in 1991 at all educational levels and in both the PS and SL curricula streams will be characterized by individualized learning. Individualization of instruction will very likely be characteristic not only of science education, but of all areas of study in the schools and colleges of the last decade of the twentieth century. Whereas the customary unit for arranging instruction today is a group of students organized as a class or a course, the focus in 1991 will be on the individual student and his progress through sequences of learning experiences. For the learning of science, varied resources and materials that are maximally adapted to individual needs and learning styles

will be provided, so that the student may have available numerous alternative pathways for attaining the successive proficiency levels. The establishment of proficiency levels, each based on progress normally anticipated during one year of science study, and the setting of similar proficiency levels for other learning areas, will have made it possible by 1991 to discard the present system of elementary and high school grade levels, based on the number of years the child has attended school. In a non-graded school, every student will be able to persue his study of science at a rate that is best suited to his individual capacities. To plan and operate such an individualized learning system, the science teacher of 1991 will require assistance both in management and instruction, and this support will be provided through the necessary and appropriate electronic computer installations serving the schools.

Beginning in the kindergarten of the elementary schools of 1991, all students will study in a basic science education program, running through nine proficiency levels. The science program will be comprehensive and will be designed, in part, to provide each student with some basis in experience for deciding on whether or not he should choose to go into the PS Stream. However, more objective information for making this decision will be provided by the student's performance on the Career Prediction Test Battery, taken by every boy and girl during his final year in the elementary school. In consultation with career guidance counsellors, the student and his parents will be able to choose either a high school in the PS Stream or a high school in the SL Stream.

The high schools in the SL Stream will accommodate approximately 85 per cent of all the students. Approximately 15 per cent of all students will attend the high schools in the PS Stream. Since the curriculum of the high schools in the PS Stream will be highly specialized and demanding, attendance

at these special schools will be determined by a student's strong interests and high predicted probability for a career in science, medicine, or engineering, not by the prestige of the school's selectivity. The high schools in the PS Stream will be associated with, and may be located near, a college or university or industrial organization, which has a direct interest in the careers of the students who attend these schools. Appropriate cooperative arrangements and programs will be established between each school in the PS Stream and its associated collegiate or industrial institution. When this pattern of science education is fully implemented, there will be perhaps 3000 special high schools in the PS Stream throughout the country. By using regional attendance districts as the basis for the geographical areas to be served by particular schools, no child who has the interest and the potential to succeed in the PS Stream will be denied the opportunity to attend one of these special high schools.

The high schools in the SL Stream in 1991 will be organized somewhat like the comprehensive high schools of today, but they will not serve those students who are heading toward careers as scientists, physicians, or engineers. A broad variety of curricular offerings will be available to the students in schools in the SL Stream, since these students represent a great range of aptitudes and interests and are headed toward many different future careers. One element, however, will be common in the learning program of every student in these high schools: he will study science in each year of his secondary school experience. His program of science studies will be quite different from that offered in the schools in the PS Stream, but the required study of science will be just as vital to his education as the required study of English. Opportunities for additional science study beyond the basic requirement may also be offered in the high schools in the SL Stream as need and demand may

dictate. Yet, the science offerings in these schools will not be nearly so ample or diverse as those in high schools in the PS Stream. Here the learning program of each student will call for the study of science and related mathematics during one-half to three-fifths of the total time of his high school education.

With this background about the pattern of science education that can be expected in American elementary and secondary schools in the last decade of this century, it may be enlightening to take a tour, in imagination, of several educational locales in that future time.

Elementary School Science, 1991

Miss Edwards is a science teacher in the intermediate unit of the Skylark School. (The school, incidentally, is not brand new, but was built seven years ago in 1984. Like most elementary schools constructed in the past decade, the Skylark School contains both a primary unit for the younger children and an intermediate unit for the children who are studying toward proficiency levels 6 through 9 in the several areas.) Miss Edwards is young, fairly new to teaching, and perhaps a little more glib in talking about the elementary science curriculum than some of the other teachers on the science staff of the intermediate unit.

"Most of these children have passed the 6th proficiency level," she replies to our question. "They're progressing at about an average rate, though two of the girls seem to have a real aptitude for science and are working on some very original projects. All the children are excited about their science investigations, I'm happy to say, and they're coming around to seeing for themselves the value of science in this modern age. And, after all, I think those are the main aims of science instruction in the elementary school -- to generate in

every child the excitement and joy of investigating the natural world and to build up a wholesome appreciation of the importance of science in society today."

"At Skylark School," continues Miss Edwards, "the children have science every day beginning in the kindergarten. I believe that all elementary schools in the country today give some time to science every day for all the children. Besides this, of course, science reading materials and stories about scientists have a large part in the reading development program in our school's primary unit. Our primary unit and this intermediate unit are organized on the "non-graded" principle, which was pioneered in American elementary schools in the 1950's, so that each child may progress at his own learning rate in each area of the curriculum. In science, for example, this means that some children enter the science program of the intermediate unit during their fourth school year after kindergarten, most of the children enter in their fifth year, and a few start the intermediate unit's science program during their sixth year. Of course, our school's total science curriculum from the kindergarten on up is built around an integrated sequence of learning experiences for the children. The plan for our total science curriculum was brought up to date by the Skylark School staff only two or three years ago."

Miss Edwards deftly punches a code number on the console of the televiewer next to her desk, and we obtain a display of the school's current science curriculum plan. We note that this plan follows rather closely the Revised Recommendations for Elementary School Science, published by the National Science Teachers Association in 1987.

"Our science curriculum is individualized and reflects our belief that every child must obtain a basic literacy in science by the time he leaves the

elementary school, just as every boy and girl must develop competence in using the English language and obtain a functional understanding of mathematics. The science curriculum has two principal emphases: the processes of scientific investigation and the major conceptual schemes of science. From what I learned at the university about the history of science education, I understand that these same emphases for science curriculum planning were already being recommended nearly 30 years ago, for instance in the 1964 publication of the National Science Teachers Association, Theory into Action. Well, the intervening years have certainly put these ideas into action in elementary school science."

"One of the starting points for the planning of our science curriculum was the recent insights obtained by behavioral scientists into the child's physical, emotional, and intellectual development as he grows. This information was used to help us decide on which scientific processes and concepts would be placed at different stages of the curriculum, and also to help decide on which activities and investigations children could carry out most profitably at different times. Naturally, since each child is an individual who learns best in his own unique way, no decision we make about ordering of learning experiences is infallible, but we can make better judgments today than we could have in the past. At the same time, our science staff still believes that we should have on hand at least two or three alternative ways that the student can use to learn every important idea and skill in the science curriculum. In working with children, I've found that the processes of scientific investigation are widely applicable to all disciplined mental activity, not only to science. This suggests to me that, by emphasizing such processes as observation, classification, measurement, communication, hypothesizing, theory-building, we have the opportunity to coordinate the children's learnings

across several curriculum areas in the total program of Skylark School."

Miss Edwards interrupts our conversation now, since several students have signalled her for help. Walking around the large laboratory-classroom to the various student stations, we see the children, individually and in small groups, busily working on a number of different investigations. Every child seems to be following a plan of study that interests him and that he has worked out for himself, with Miss Edwards' help. The laboratory-classroom is quite fully equipped and has ample space for each student to set up his experiments so that they will not be disturbed. Miss Edwards points out several original investigations that were suggested and designed by the students carrying them out, but she admits that most of the children are doing experiments that arose out of problems discussed in the students' study guide. Returning to our previous conversation, Miss Edwards continues:

"As you see, the children get a good deal of experience when doing their own investigations with processes that are the same as those scientists use to advance science. This is how we make real our emphasis on the processes of scientific investigation. The second emphasis in our curriculum, as I've already mentioned, is on the major conceptual schemes of science today. These major concepts now held by scientists have some permanence over time, even in the face of the continuous changes in science with its rapid accumulation of new information and constantly shifting ideas. In our curriculum plan, the concepts, subconcepts, and topics which the children study are all a part of a development leading to the several major conceptual schemes of today's science. It's very interesting, you know, that forward-looking science educators of 25 years ago argued that major conceptual schemes of science could be used to structure the subject-matter content of the school science curriculum, and this

idea has persisted until today."

"I think it's also quite interesting that the major concepts proposed in the 1960's for organizing the elementary school science curriculum were so limited. Science has certainly grown tremendously since those days. Some of the old conceptual schemes can still be recognized in those we use today, but they've all been expanded and modified by new scientific understanding. The major conceptual schemes emphasized in the development of our science curriculum include these ideas: intergalactic relativity and complementarity, interactions of force fields, organizational levels of living and non-living systems, physical and biological interactions in ecosystems, functional evolution of living and non-living forms. Naturally, the full development of these conceptual schemes through all the levels of our science curriculum also includes the applications of the various concepts and ideas to the practical affairs of everyday life. And that's another way in which the major concepts used in the 1960's were limited; it seems that most people then thought of science only as some form of pure knowledge. I understand that the application of science to the benefit of man used to be considered as something separate from science even as recently as 15 years ago. Don't you think that's strange?"

Career Counselling Session

The guidance and counselling suite at the Skylark School is located across the hall from the principal's office. Tom, who has just turned 14, is in an interview with his counsellor, Mr. Clark.

"I'd like to talk with you this morning, Tom, about the results on your Career Prediction Test Battery."

"Yes, sir. I imagined that we'd have to talk about that pretty soon. I have to decide about the high school I'm going to go to by the end of April."

"That's an important decision, Tom. The purpose of the test battery you took was to give you some information to help you make a good decision. You took tests which measure various aspects of your aptitudes, interests, personality, and knowledge. Your school records also contain data about your family background, your achievement in different subjects, and your activities here. From research studies on career development patterns, we've learned how to put all these data together to make some pretty good predictions about the kinds of careers you're suited for and where you're likely to be satisfied. Now remember, Tom, you're not forced to react in any particular way to the predictions I'm going to give you, but you may want to add them to other information you have as you think about your plans for the future."

Tom doesn't ask about the reliability of the career prediction information he is about to receive, but if he did, Mr. Clark could tell him that the predictions have been found to be remarkably accurate. Of the cases where a student has chosen to follow an educational program which would prepare him for the career field that showed the highest probability loading in the predictions, nearly 90 per cent eventually enter that career as young men and women. The

predictions are based on long-term studies of career patterns and of the content of the education needed to enter particular careers. The success of the predicting system is largely due to the application of computer technology to career guidance.

Much of the basis for the system used today was provided by the research of Project TALENT. Beginning in 1960 with the collection of data from students in a five per cent sample of all American high schools, Project TALENT continued to follow the subsequent educational and occupational careers of nearly half a million men and women. The last of the 20-year follow-up studies was completed in 1983, and Project TALENT's final report was issued in 1985. Long before this, however, countless special studies using the extensive Project TALENT data had been carried out, and many techniques applicable to career guidance were developed. The computerized career guidance system now in use was developed by the Project TALENT staff, but it also takes into account the research contributions of numerous other behavioral scientists.

Without worrying about the technical details of how this is achieved, what each student receives as output from the computer is a table showing the probability of his future membership in each of six broad occupational groups. The six broad occupational groups are:

I. Physical Science Group, including physical scientists, engineer mathematician

II. Biology-Medicine Group, including biological scientist, physician, nurse

III. Humanities Group, including social worker, teacher, literary critic

IV. College-Required Business Group, including lawyer, accountant, industrial manager

V. Non-college-Required Technical Group, including engineering aide, medical technician, skilled worker

VI. Non-college-Required Business Group, including clerical worker, salesman, service worker

Supplementary tables on the computer print-out give estimates of the statistical reliability of the predictions of probable occupational group membership.

"Gosh, this surely gives me an idea of what my chances are for getting into different kinds of work," says Tom after listening to Mr. Clark's explanation. "Where do we go from here?"

"Well, Tom, the next thing we ought to do is to bring some more people into this conference. Is your mother at home? Is your father at his store?" Tom nods twice, and Mr. Clark turns to his secretary. "Mrs. Smith, would you please ring in Tom's mother and father on the televiewer."

A High School in the PS Stream

Just published is the new "Student Handbook" of the Paul Sabatier High School for the school year 1991-92. The prose in a student handbook can appear pretty d[illegible]ary. But not to Frank. He is a Freshman in the school, and he's reading his copy of the Student Handbook with rapt attention.

On the opening page is the Principal's Message, which contains, as in every previous edition of the Handbook, a brief review of the school's founding. Paul Sabatier High School was founded in 1981 and was the first high school in the country to serve students in the PS Stream. Paul Sabatier (1854-1941) was a French scientist, winner of the Nobel Prize in chemistry for his work on catalytic hydrogenation, and his name was chosen for the school to call attention both to the international character of science and to the interdependence of science and technology. (Applications of Sabatier's work on catalysis made possible the economical manufacture of edible fats from plant oils.) Next in the Student Handbook is a statement from the president of the university associated with Paul Sabatier High. The president's message

mentions the cooperative arrangements for advanced study and for laboratory work experiences on the university's campus and also cites the extensive program of supplementary seminars given in the high school by visiting university scientists and other faculty members. With a calculated flourish, the president ends his statement with a quotation from Pascal:

> "That which is known is like a circle pushing against the unknown. The larger the circle of knowledge the greater the awareness of the unknown."

Frank flips the pages of his Student Handbook to the section which describes the required core program of the school. He quickly discovers that every student is required to study Communication during every year. (Communication studies are roughly equivalent to what was taught in courses called "English" in former times.) In addition, every student must study Social Sciences, Mathematics, and a Foreign Language until he attains the 12th proficiency level in each area. Attainment of the 12th proficiency level, both in Physical Science and in Life Science, is also required of every student. But, Frank learns, before beginning Physical Science and Life Science, he must study the Science Alpha sequence. Frank turns to the description of this sequence and reads:

"Science Alpha is an exploration of fundamental ideas in science. The student re-examines what he has learned about these ideas in his previous study of science, and he is confronted with questions concerning what knowledge is and what can be known. Ideas explored in Science Alpha include: length, mass, force, time, growth, life, mind, man. Science Alpha raises many questions, but does not provide final answers."

Confronted with this summary of the beginning science sequence, Frank gains the impression that his study of science at Paul Sabatier High School

will not be superficial. This impression is not dispelled as he reads the description of the required program of study in science.

"The core program consists of the sequential study of the disciplines in Physical Science and in Life Science. Students study in both areas in parallel, and several alternative learning experiences are always provided. The study of each discipline emphasizes the structure of that discipline and its relationships to other disciplines in Physical Science and Life Science. (The study of the structure of a science discipline includes the delineation of its subject matter, the principles of inquiry appropriate to the subject matter, and the development of the key concepts used to organize the subject matter.) In the main, the several disciplines are introduced in the approximate order of their historical appearance in modern science. This order helps each student to develop some notion of the evolution of scientific thought. Once a discipline is introduced into the sequence and its historical development is reviewed, the treatment of the subject matter is in the terms of the present-day structure of the discipline. In Physical Science, the sequence of disciplines studied begins with Astronomy; in Life Science, the sequence begins with Human Biology. The subject matter of each of these disciplines early engaged man's attention for investigation by processes of observation and reasoning. In the initial study of Astronomy and Human Biology, however, only the data and the problems of each discipline are developed, since the present-day structure of both these disciplines incorporates much of the structure of all the other disciplines in Physical Science and in Life Science, respectively. For this reason, the sequence of studies in Physical Science returns in the end to the discipline of Astronomy, and the sequence in Life Science culminates with a return to the discipline of Human Biology. These disciplines are now thoroughly treated, completing the sequence of studies in Physical Science and in Life Science to

the 12th proficiency level."

Once again, there's that phrase, "12th proficiency level." Frank is not sure he knows exactly what it means. Julie knows. Julie is a Junior at Paul Sabatier High, and she's happy to share her wisdom with a puzzled Freshman.

Julie explains to Frank that the school has clearly specified objectives for every area of study. In Physical Science and in Life Science, these objectives specify the understandings of concepts, the competencies in investigative procedures, and the inter-disciplinary syntheses that every student is expected to master. In addition to the statement of objectives, the standard of proficiency in each objective is also specified. Students at Paul Sabatier High generally attain this level of proficiency in most curriculum areas sometime during their junior year, i.e., the twelfth year of school counting from the beginning of kindergarten. Hence, the name "12th proficiency level," though some students may attain the specified level of proficiency in some curricular areas before their twelfth year.

This acceleration is possible because so much of each student's learning is on an auto-instructional basis. The school's learning centers have full facilities to give students ready access to various auto-instruction media, including books, films, videotapes, data files, computer-programmed lessons. At least one science teacher is always available in each learning center for conferences with students. The science teachers also organize regular discussion groups, give guidance to students in their laboratory investigations, and help each student to evaluate his own progress. Together with the student, the teachers certify when he has achieved the 12th proficiency level in Physical Science and in Life Science.

"Wait until you become a Junior!" exults Julie for Frank's benefit. "After you've gotten your proficiency certification, you can elect all kinds of exciting science electives. There are advanced sequences offered here at the school in most science disciplines, and you can also go across to the university if you want. The second half of junior year and most of senior year is wide open for science electives, so you can really concentrate on a special field that interests you. Most kids take four or five sequences in their special science field before they graduate from high school. Some take as many as eight."

A High School in the SL Stream

As on every Tuesday afternoon, a vigorous discussion animates the meeting of the science department of the Samuel Langley High School.

"We're being old-fashioned with our present science program," Don Baker is saying. "All of our students now study basically the same science sequence. Even though all students in this school are in the SL Stream, there's great variation in their aptitudes, interests, and future career plans. Sure, every student can progress at his own rate and can choose alternative learning materials, but I think we need to set up different science sequences for different students to match the careers they're heading toward."

"I can't agree with that," puts in Betty West, who teaches Freshmen and Sophomores. "You see the kids, Don, when they're Juniors and Seniors. Their future plans are pretty well jelled by then. That isn't so for many of them in the first two years of high school. We can't plan several different science sequences without having more definite information."

Jim Howard comments, "I think that different science sequences would be very hard to administer."

"Administrative problems shouldn't keep us from having a good program," counters Don Baker. "We have enough experts in administration at this school who can worry about these things. Besides, our computer system could manage four sequences as readily as it does one. It's up to us to decide on what's most appropriate for different students to learn in their required science studies. Broadly speaking, there are four groups of students, according to their future career plans, at Samuel Langley High. It makes sense that there should be a definite science sequence matched to each group of students. In other words, we should have four different science sequences, at least for the Juniors and Seniors."

"What a complicated mess that could be!" exclaims Jim Howard.

Betty West nods her head in agreement. "I think we should be careful about rushing in and making changes we might regret later on. After all, the science program we have now takes care of kids with different aptitudes and interests. First, there's the basic sequence with its three underlying themes: the interrelationships among the science disciplines, the historical development of scientific ideas, the interrelationships between science and the general culture. Study of the units of the basic sequence normally takes a student only about half of each year. For the rest of the time, he chooses and studies some of the optional units that interest him. The optional units extend particular topics in the basic sequence, and they vary in difficulty. We now have more than seventy optional units available, and we're developing additional units all the time as students want and need them. Honestly, I really don't see anything wrong with our present science program."

"But why should we be so antiquated?" mutters Don Baker. "The pattern we're using in our science program is very much like the pattern used in the

old Project Physics course of 20 years ago. After all these years, we ought to be able to do better. And we could too, if we weren't held back by a lot of antedeluvian thinking."

The chairman hastens to say, "Now, Don, I'm sure no teacher here is backward in his or her thinking. We all want to have a science program that's best for the youngsters. Our present program may not be the best, but it has some strong points in its favor. A high school science program is supposed to build up from the children's elementary school science experiences. I think our program does that. A high school science program in the SL Stream is supposed to give each youngster a view of the unity of science. I think ours does. A high school science program ought to include some study of current scientific developments and how they affect the society. Our program does. And our program provides individualization in learning rate and through alternative materials designed for different learning styles. I agree that it's always possible to improve, but we must keep in mind that our main purpose is to develop scientifically literate young men and women. There's no one way that's necessarily the best way to accomplish this. The important thing is that we keep on thinking and keep on planning, so that we may come up with what's best for the youngsters at Samuel Langley High School. -- Now, Betty, would you like to carry on with the discussion?"

The Impact Debates

A man from the television crew rushes by us as we enter the civic auditorium. In the lobby we pass reporters from the newspapers and national magazines. We're not suprised. Everyone follows the Impact Debates.

Tonight are the regional finals. Two teams are entered from Paul Sabatier High School, one team for the affirmative, one for the negative. Samuel Langley High School also sent two teams, one for the affirmative, one for the negative. Each team is the top team for its side from the school competitions. The two top affirmative and negative teams in tonight's competition will go on to the national finals of the Impact Debates.

The Impact Debates are a part of the efforts of science educators to stimulate communication between high school students in the PS Stream and students in the SL Stream. Part of the same effort is the international magazine of student opinion, Impact, published weekly at Paris. (This publication is descended from the journal, Impact of Science on Society, founded by UNESCO in the 1940's. It became a student's magazine in 1984.) Students in secondary schools all over the world contribute articles and letters to Impact, and the contents of the thick weekly issues of the magazine are widely discussed. The pages of Impact are open for discussions of all topics connected with the interplay of science and culture.

We pick up copies of the special issue of Impact that features articles about the current proposition of the Impact Debates:

> "Resolved that the United States shall immediately undertake preparations for a manned space flight to Jupiter."

The main issues in this debate is what use to make of the nation's limited funds for space exploration. Many different projects are now possible. Which

has the greatest scientific value? Which has the greatest human value? -- Planet Mars is practically unexplored, despite three manned missions there since 1989. Other manned missions could be sent to Mars to learn more about our most Earth-like neighbor. But other planets should be explored also. Unmanned probes to Jupiter haven't yielded much information. A manned landing on Io, Jupiter's second nearest satellite, is now technically feasible. But funds for a manned landing on Io could be better spent to probe outside the solar system. Unmanned probes can now be sent toward a nearby star, say Alpha Centauri. Such probes could relay back valuable new data. Possibly a new system of planets would be found. Possible a planet with intelligent life. --

These are some of the issues that will come up in the Impact Debates.

Science at the College Level

Let us return now from the tour of future educational locales to a consideration of the extension of the science education pattern of 1991 beyond the high school level. The two curricular streams leading through the PS and SL secondary schools will each make corresponding connections at the college level. Students in the PS Stream will enter into their undergraduate education already possessing an adequate level of preparation for the study of various science specialties. Soon after entering college, the programs of study for students in the PS Stream will begin to diverge as they elect to prepare themselves for different areas of science or for medicine or for various branches of engineering. Early specialization will lead more rapidly than in former times to the completion of requirements for the bachelor's degree and, for many students, to the early commencement of pre-professional training. This desirable outcome will be one of the significant advantages derived from the clear differentiation of two curricular streams in the total pattern of science

education.

Students in the SL Stream who go on to college will usually study at the same large college or university where there is also a science program for students in the PS Stream. This will not always be the case, however, since the number of collegiate institutions which serve only students in the PS Stream, such as today's institutes of technology, doubtlessly will increase considerably by 1991. Moreover, there will also be in 1991 many smaller colleges, descendants of today's liberal arts colleges, which serve only students in the SL Stream. In any event, whatever the institutional arrangements may be, the science courses available to college students in the SL Stream will be specially designed for these non-scientists to broaden their understanding of science. Included in the offerings will be numerous courses, each taught by a specialist who can depict skillfully the essential ideas in his field and the current research problems in it. Having obtained a basic grounding in science through his elementary and secondary school studies, the student would be able to comprehend such discussions, if they are properly presented, and could enrich his knowledge about diverse areas of science that he finds attractive. The availability of many such "essentials" courses, from among which a student in the SL Stream may elect to study several during his college years, will help every student to keep up his interests in science, a habit that is one aspect of the behavior of a scientifically literate person.

The projected pattern of two curricular streams in the high school years will make possible a renaissance of science teaching in the colleges. Students in the PS Stream will come to college well prepared in science and ready to pursue the study of specialties. Instructors will have the opportunity to work with committed students who may soon be their co-workers in research.

For the student's study of the fundamentals of the science specialty he selects, computer-assisted instruction and other auto-instructional devices will be widely used. The lecture room will no longer be a place for dispensing information, but rather it will give the professor the opportunity to teach and to challenge. In terms of the productivity of their pre-professional programs, the PS Stream colleges will be more efficient in 1991 than today. Despite the increased dimensions of science in that future time, undergraduate programs of study may be completed, at least in some science fields, in three years or even two and a half. Contributing to this greater efficiency is the fact that students in the PS Stream will enter college from high school with science preparation comparable to what college students obtain today by late in their sophomore year.

The colleges in the SL Stream will also witness a revitalization of science teaching. Gone will be the need for today's "general education" science courses to patch up the deficiencies in the students' science background. Instead, the student will come to college with a balanced view of science and its roles in contemporary society. He will be ready to pursue studies in certain fields of science, according to his interests and in specially-prepared "essentials" courses, and he will be able to participate intelligently in discussions with scientists. Seminars led jointly by scientists and philosophers, by scientists and economists, by scientists and other creative artists will be common.

From among the students in colleges in the SL Stream will come, in 1991 as today, most of the next generation of teachers for the elementary and secondary schools. Many of these students who have a particular interest in science will become the science teachers in elementary schools and in high schools in the SL Stream. This arrangement is particularly appropriate, since it perpetuates the emphasis on the development of students' scientific literacy.

Science teachers for high schools in the PS Stream will be drawn from colleges in the PS Stream. A specialty for science teaching will be available in the PS Stream at the college level, and students will be able to elect this specialty, if they possess the necessary background and qualifications, as for any other specialty. With this arrangement, a continuity in the teaching of science from the secondary school upward is also provided for the PS Stream.

One other general feature of the science education pattern of 1991 should be noted. It may appear that the differentiation of all students into the distinct PS and SL Streams is too rigid and that, on the basis of a person's decision at age 14, his destiny is sealed. Actually, this is not so. Opportunities for a student to switch from one curricular stream to the other will be built into the pattern. Predictions of probable adult occupational group membership on the basis of elementary-school data are not infallible, (though by 1991 those predictions will be quite reliable) and a student's interests change with time. Thus, some changes across curricular streams are expected. One anticipated change is that more students will move out of the PS Stream than move into it, so that a contraction of the proportion of students in this curricular stream will be observed over the years. (In fact, the approximately 15 per cent of all students who start in the PS Stream at the beginning of high school is about twice as large as the proportion expected to eventually complete professional training as scientists, physicians, and engineers.) At least two principal stream transfer points will be available where career decisions may be re-evaluated. In the junior year of high school, transfer from the PS Stream to the SL Stream or vice versa may be effected with an additional 6 to 12 months of intensive study to compensate for the difference in the program the student has taken up to that point. Similarly, in the sophomore year of college, additional intensive study for 9 to 18 months will make

it possible for a student to move from either curricular stream into the other. In this way, then, some modicum of flexibility is provided for in the pattern of science education of 1991.

Will these predictions about the science education of the future be fulfilled? Only the passage of time and events will tell us. Yet, educators with convictions and commitment can mightily influence the course of events. This paper has attempted to extrapolate through time some present-day trends in science education and to balance these trends against the demands of society and the needs of people in it. By looking to the future, we may be able to shed some light on how to proceed in the present.

Footnotes

1. The year 1991 in the title of this paper is used as a convenient indicator for the last decade of the twentieth century. Thus, the title should not be interpreted to imply pinpoint predictions for a particular year in the future. Based in part on a presentation in the "Teaching and Learning, 1991" lecture series at The University of Chicago, this paper seeks merely to assess key aspects of science education today and to suggest productive directions for the teaching and learning of science during the next quarter of this century.

2. Numerous projections of trends in the closing third of the twentieth century have been published recently. One of the most interesting of these studies in reported in Herman Kahn and Anthony J. Wiener, The Year 2000, (New York: The Macmillan Co., 1967).

3. Quoted in Bentley Glass, "Renascent Biology," The School Review, vol. 70, 1962, p. 19.

4. Paul DeHart Hurd, "The Scientific Enterprize and the Educated Citizen," a paper presented at the National Science Teachers Association Regional Conference, San Diego, California, 17 November 1966, p. 2.

5. For an illuminating analysis of this process, see Francis S. Chase, "School Change in Perspective," in John I. Goodlad, ed., The Changing American School, 65th Yearbook of the National Society for the Study of Education, Part II, (Chicago: University of Chicago Press, 1966), pp. 271-306.